

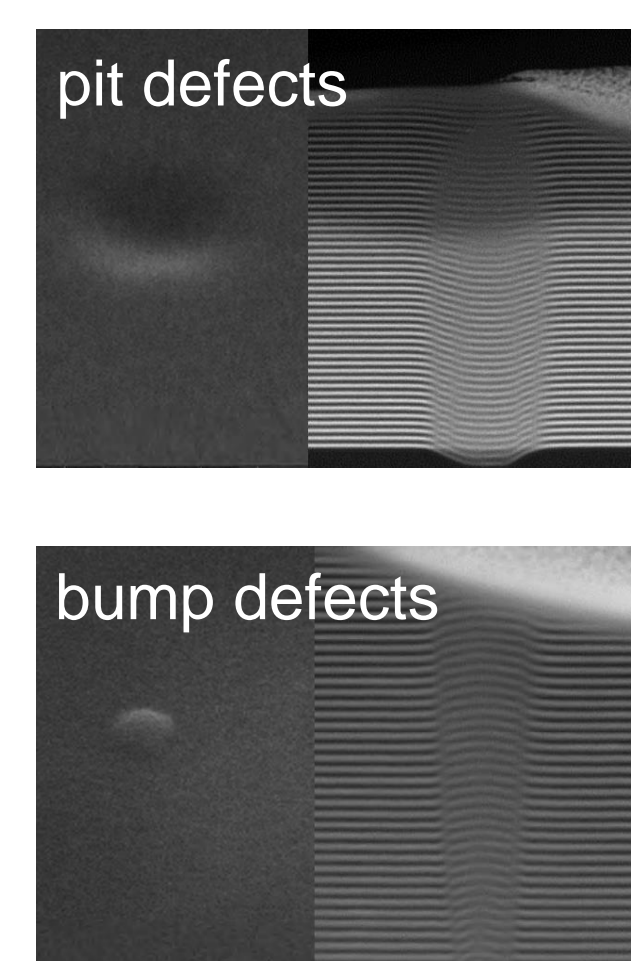
Differential phase contrast imaging for EUV phase defects inspection: A numerical study

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Introduction

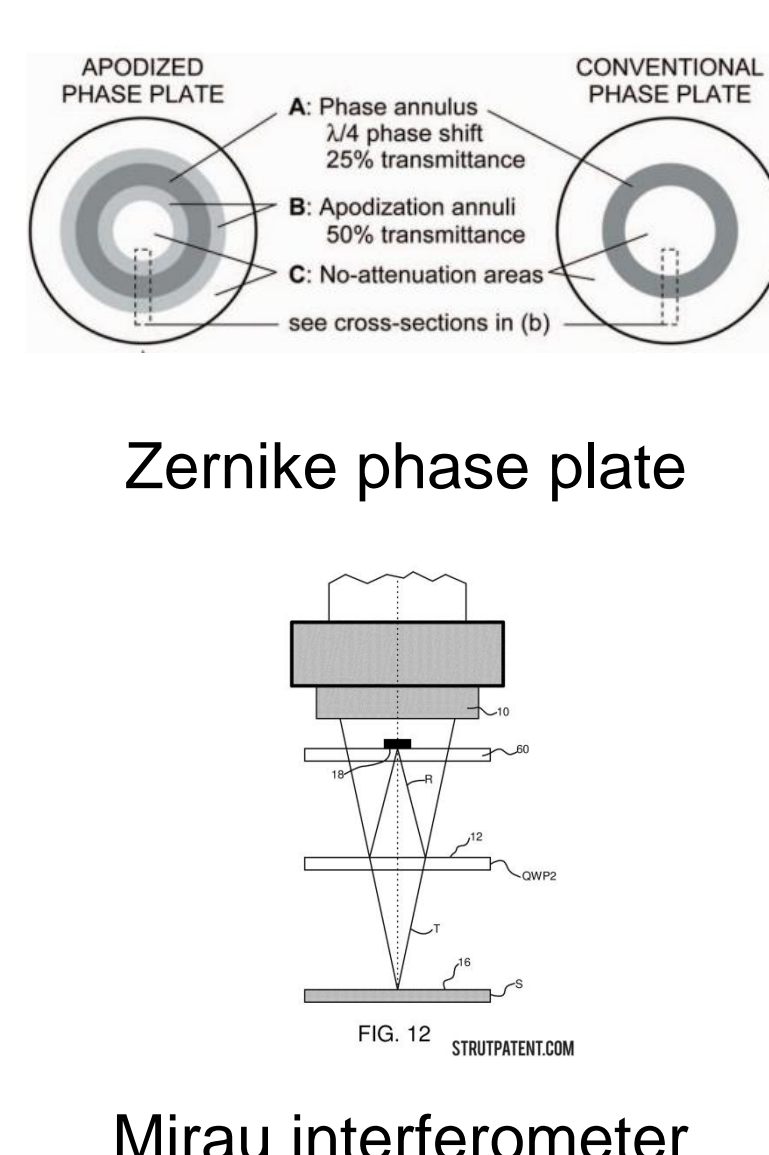
Actinic EUV photomask qualification tools such as AIMS-EUV or SHARP primarily measure aerial image intensity at wafer plane. However, in situations such as phase defects inspection, phase contrast microscopy can significantly enhance the image contrast at focal plane. Furthermore, direct and quantitative characterization of mask phase shift could benefit the development of phase shifting EUV masks and help us to understand phase jumps at absorber edge.



Phase contrast imaging

To date, all proposed and demonstrated methods for actinic phase contrast imaging of EUV mask require sophisticated optics or algorithms, for example

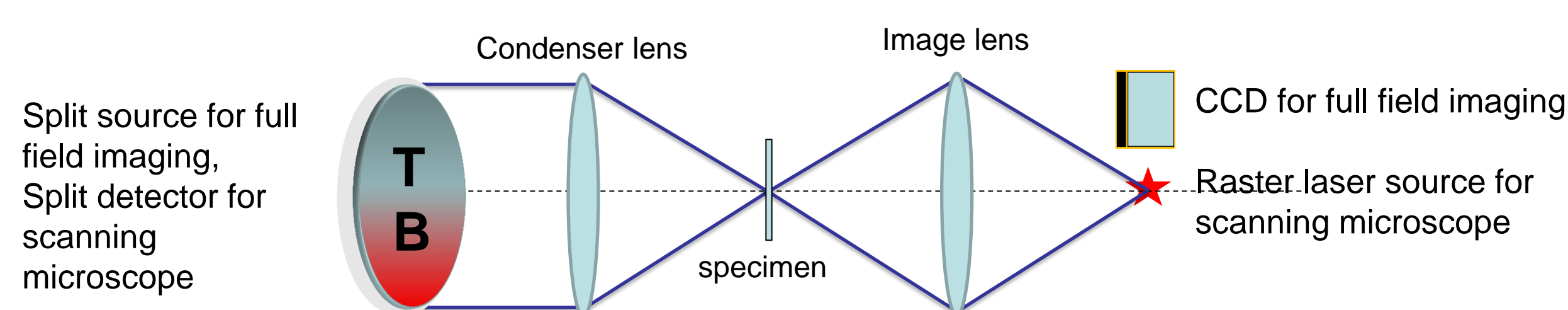
- A specially designed zone plate is needed for apodized Zernike phase contrast microscopy¹
- An EUV beam splitter is needed for interference microscopy²
- Numerical phase reconstructions from multiple images of a through-focus series³



Oblique illumination based differential phase contrast

We demonstrate numerically that asymmetric off-axis illumination could enhance the contrast at focal plane and extend the depth of focus for imaging phase defects on EUV mask. In addition to qualitative observation, it also allows us to extract the resolution limited phase profile of the defects quantitatively.

Asymmetric illumination based on differential phase contrast imaging had long been known as an effective method to enhance contrasts for unstained transparent biological samples, even before Zernike invented the phase contrast mechanism bearing his name.

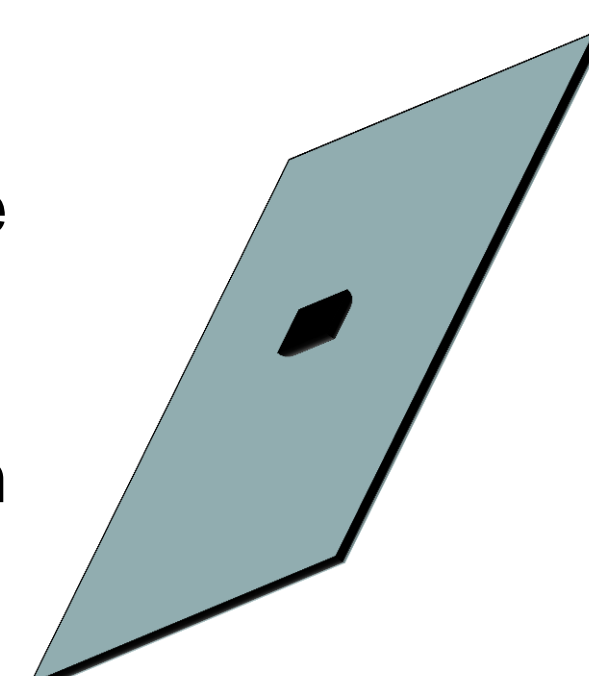


Equivalence between full field and scanning microscopy

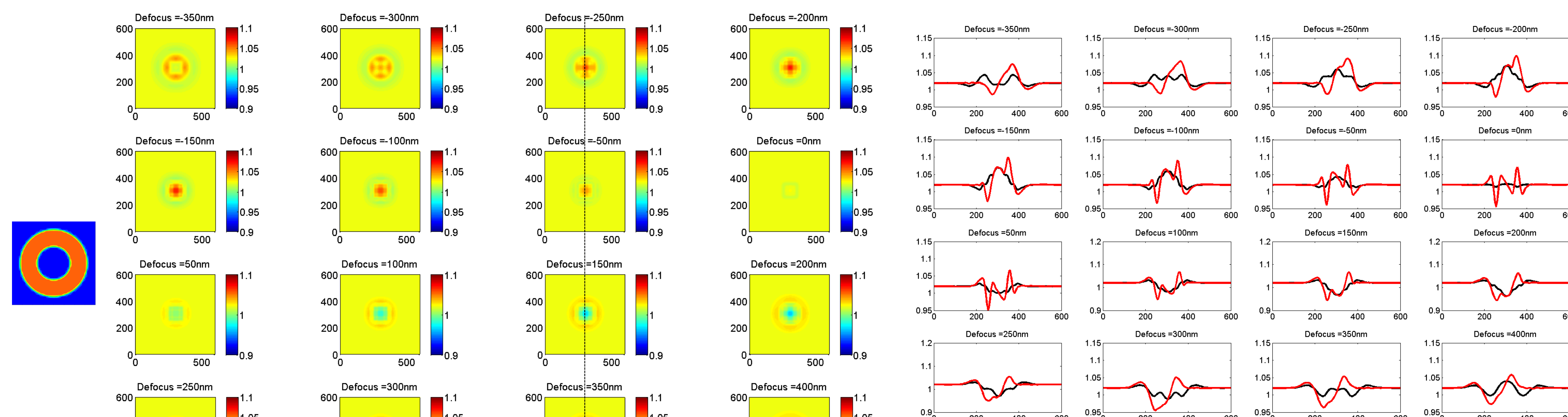
Simulation model and parameters

We simulate the aerial image of a square phase defect, 400 nm in width and 0.2 nm in height.

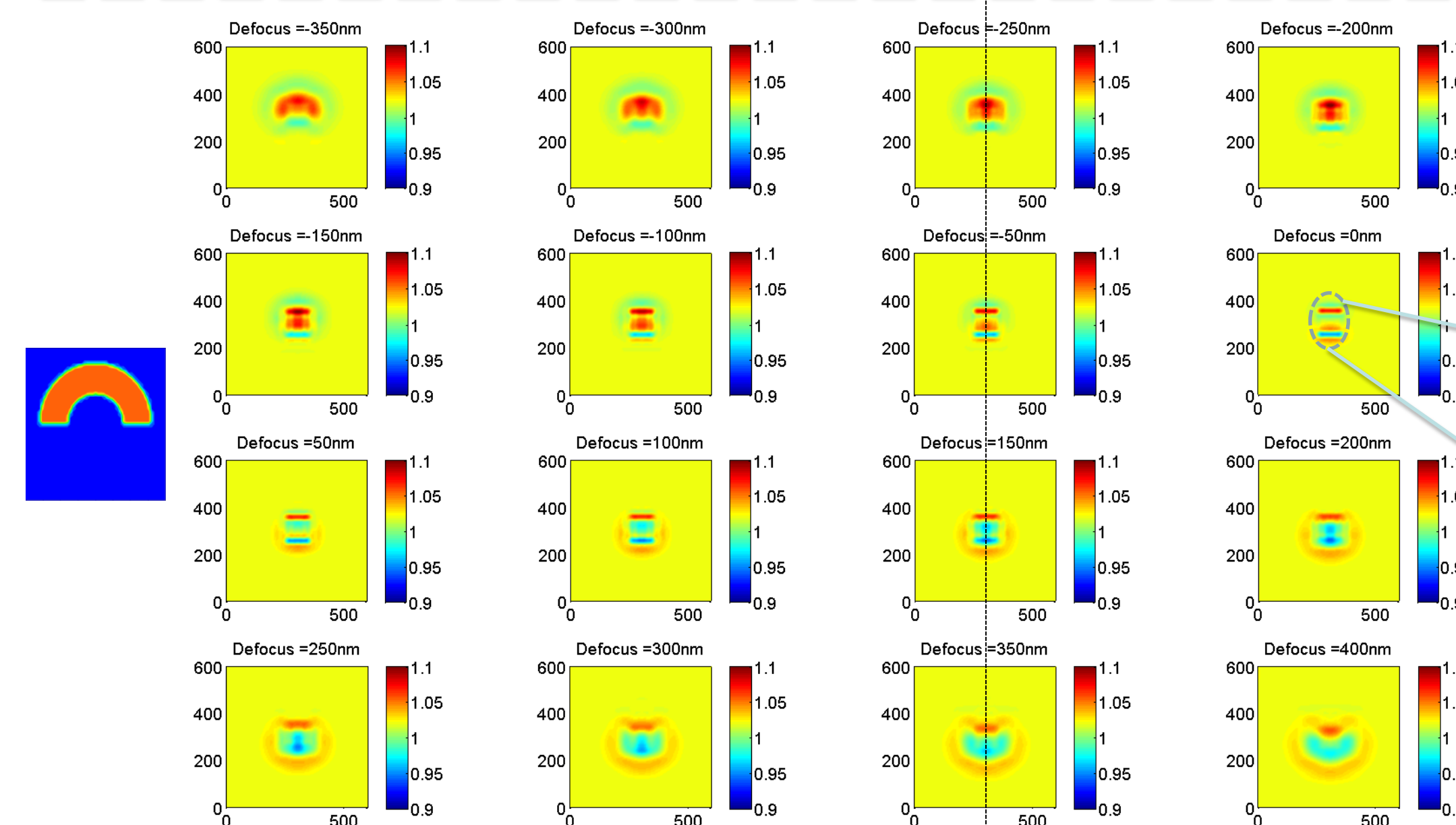
We set 4x demagnification and use Kirchhoff thin mask model in PROLITH for the simulation.



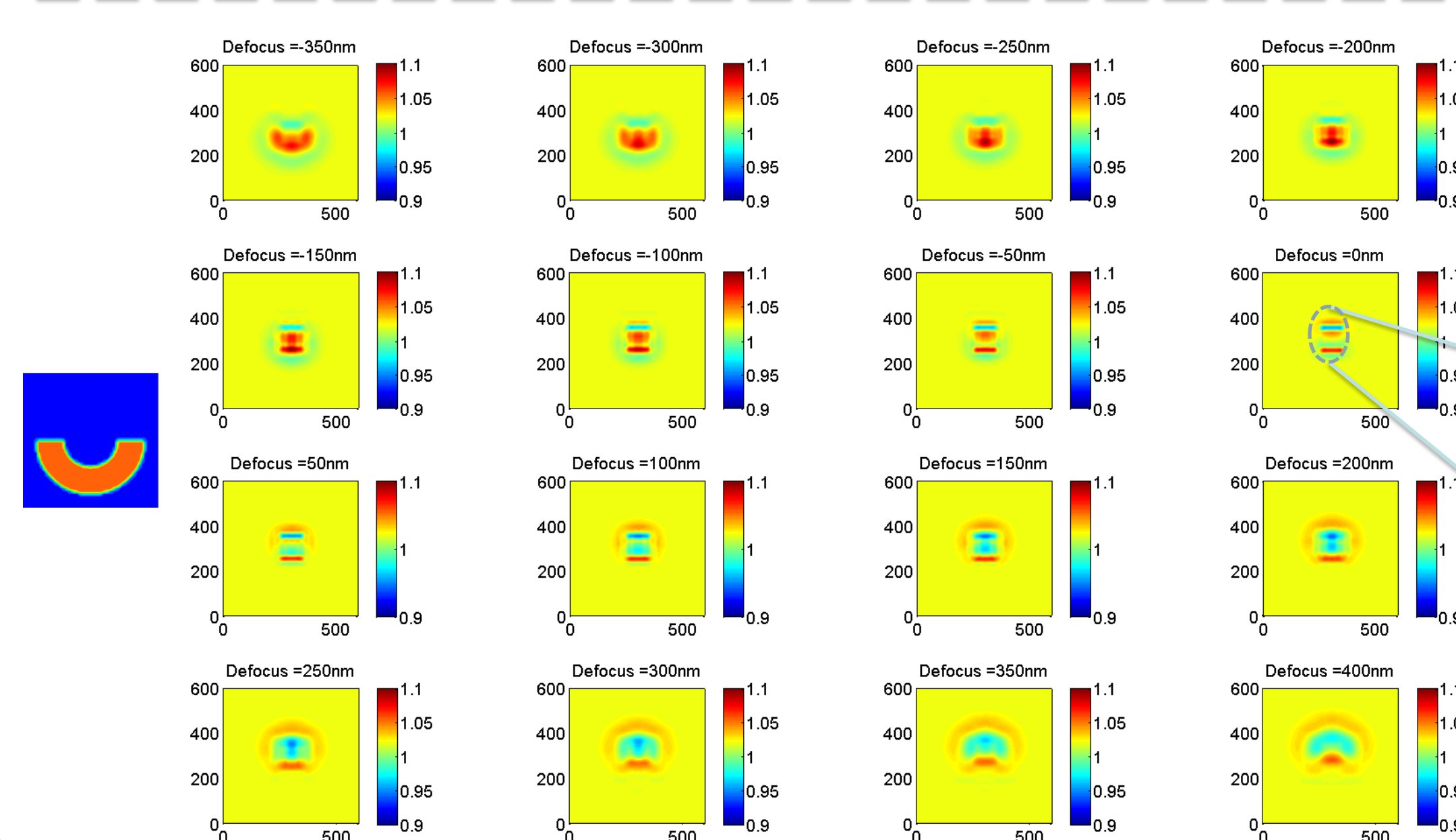
Simulation results



Through focus aerial images for annular illumination.

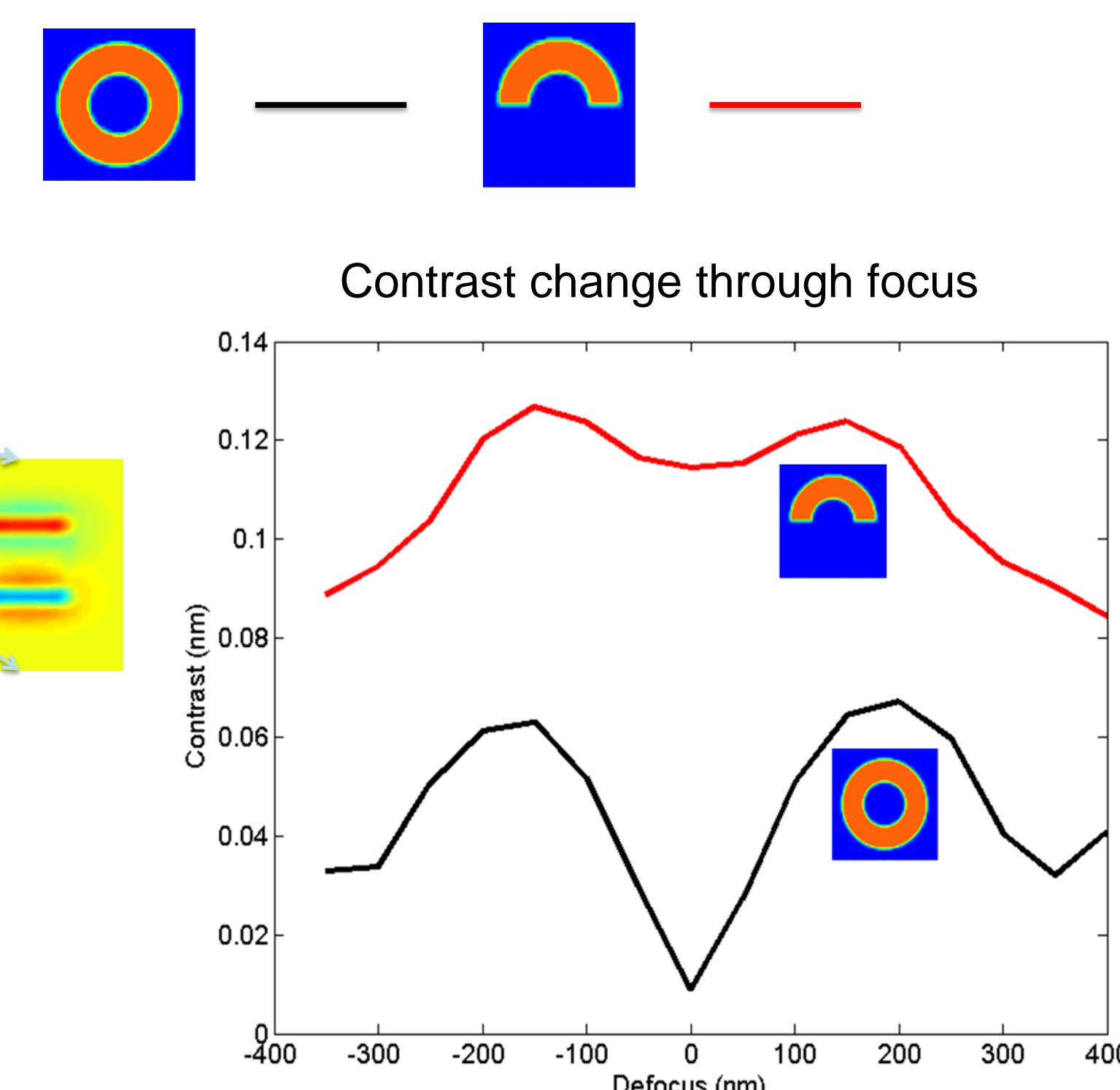


Through focus aerial images for top half annular illumination.



Through focus aerial images for bottom half annular illumination.

Lineouts of through focus aerial images for annular illumination.



For annular illumination, the contrast is minimized at the best focus, increases towards defocus locations and peaks around 200 nm of defocus.

While for asymmetric half-annular, the contrast is improved across focus including at the focal plane. The phase gradients at the top and bottom edges of the phase defect are clearly visible in the aerial image at focus.

The phase profile along vertical direction can be integrated from measured phase gradient $\frac{1}{2} (I_T - I_B) / (I_T + I_B)$

Summary and future plan

We used Kirchhoff thin mask model for our simulation, ignoring 3D mask effects such as shadowing. These effects will be included in our future work using more realistic 3D mask models.

We would also like to study the tradeoff between spatial resolution and phase contrast enhancement, as well as the accuracy of extracted phase profile from phase gradient measurements.

The scheme described here can be easily tested and integrated in full field mask inspection tools (AIMS-EUV or SHARP), as well as scanning-based inspection tools (using segmented detectors). The SHARP's capability to synthesis different illuminations with an MEMS mirror make the test straightforward.

[1] Wang, Y.-G., Miyakawa, R., Neureuther, A., Naulleau, P., "Zernike Phase Contrast Microscope for EUV mask inspection" Proc. SPIE 9048, 904810 (2014).

[2] Kazuhiro Hamamoto, Yuzuru Tanaka, Takahiro Yoshizumi, Yasuyuki Fukushima, Hideaki Shiotani, Noriyuki Sakaya, Morio Hosoya, Tsutomu Shoki, Takeo Watanabe and Hiroo Kinoshita "Phase Defect Observation Using a EUV Microscope" Proc. SPIE 6151, 615119 (2006).

[3] Mochi, I., Goldberg K.A., Xie, R., Yan, P., Yamazoe, K., "Quantitative evaluation of mask phase defects from through-focus EUV aerial images", Proc. SPIE 7969, 79691X (2011)